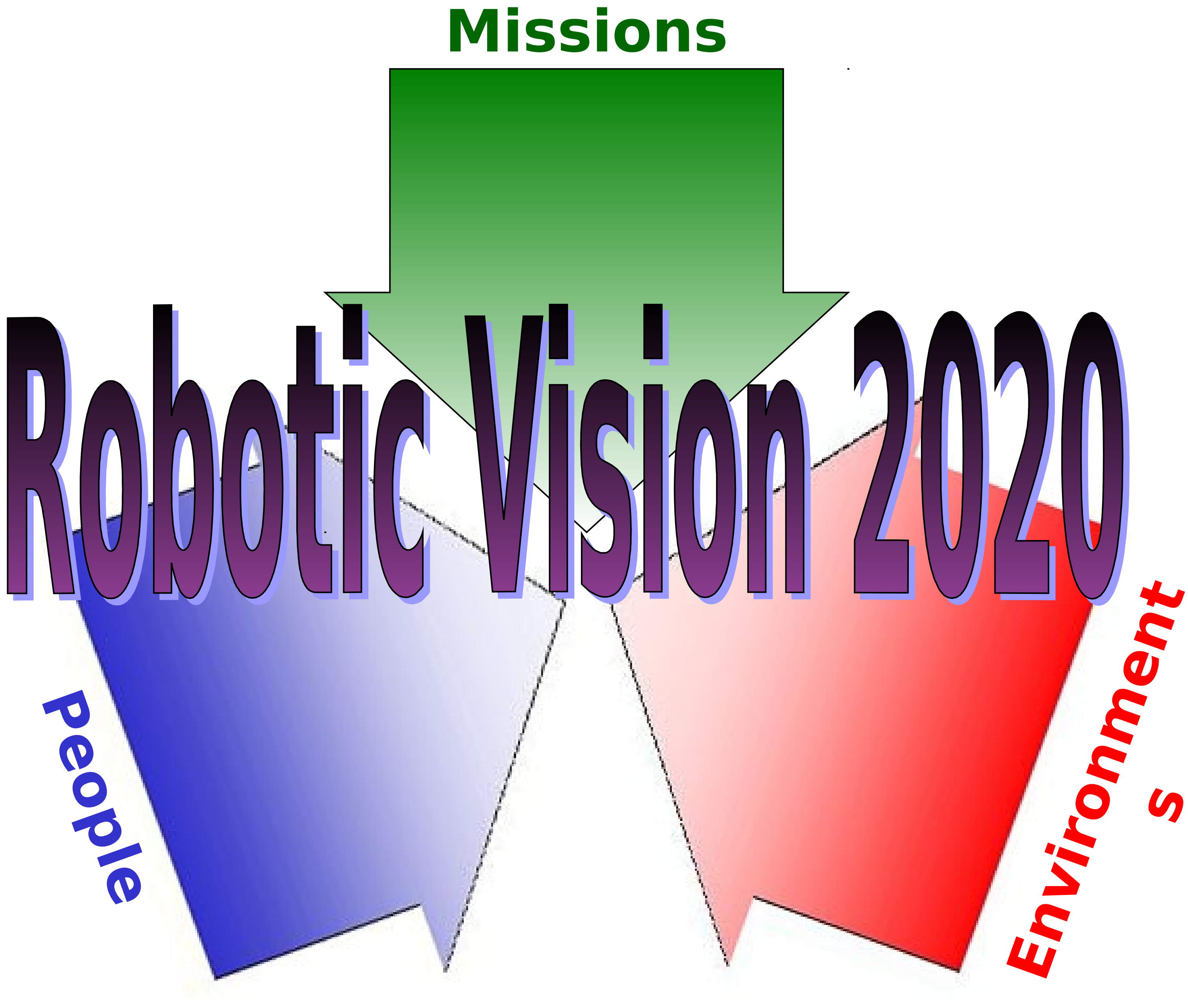

Missions
Robotic Vision 2020
People
Environment
s

“A 20/20 Vision for Robotics in 2020”

- **First cut ideas for the evolutionary development and systems insertion of revolutionary UGV robotics technology in 2015-2025**
- **In the context of the development of the Army’s Objective Force, but beyond the FCS initial deployment**
- **If not us, who? If not now, when?**

Outline

- **The target capabilities WHAT?**
- **Why an evolutionary development of the FCS Objective Force is necessary WHY?**
- **Some strategies for evolutionary development HOW?**
- **Scoping the development job HOW MUCH WILL IT COST? HOW LONG WILL IT TAKE?**

Capability Target for 2020

- **Vehicle driving capabilities at human level**
  - **Heavily perception based**
  - **Do not require GPS, but exploit it when available**
- **Initial baseline: non-military on-road "chauffeur" capability**
  - **Capabilities <u>prerequisite</u> to tank driver training**
  - **Prevent explicit military mission-based requirements from "masking" implicit underlying required capabilities**
    - **"Anthropomimetic" behaviors**
  - **A very complicated task: strawman list in DoT Driver Task Descriptions**
- **Later step: build required military behaviors and TTPs on top of baseline capability**

Driver Task Descriptions
(for DoT, 1970, NTIS PB197325)

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Driver Education Task Analysis Volume I: Task Descriptions		**5. Report Date** November 1970 **6. Performing Organization Code**
7. Author(s) A. James Knight and Bert B. Adams		**8. Performing Organization Report No.** HumRRO Technical Report 70-103
9. Performing Organization Name and Address Human Resources Research Organization (HumRRO) 300 North Washington Street Alexandria, Virginia 22314		**10. Work Unit No.** **11. Contract or Grant No.** FH-11-7336
12. Sponsoring Agency Name and Address Department of Transportation National Highway Safety Bureau Washington, D.C. 20591		**13. Type of Report and Period Covered** Final Report August 1969-July 1970 **14. Sponsoring Agency Code**
15. Supplementary Notes Volume II of the *Driver Education Task Analysis* is subtitled *Task Analysis Methods*.		

16. Abstract

This volume is the first of a four-volume report dealing with the development of driver education objectives through an analysis of the driver's task. **It contains a detailed description of the behaviors required of passenger car drivers, rated criticalities of these behaviors, and items of supporting information relating to driver performance and performance limits, enabling driver knowledges and skills, and behavior criticality.** The task descriptions have been organized in terms of the situations giving rise to the behaviors; behaviors involved in controlling movement of the car without regard to specific situations; behaviors that must be performed continuously or periodically while driving, rather than in response to a specific situation; and those off-road behaviors that are performed before driving, to maintain the car in sound operating conditions, and in compliance with the legal regulations. Volume II, entitled *Driver Education Task Analysis: Task Analysis Methods*, provides a description of the manner in which the content of this volume was generated.

Table of Contents (1 of 2)

Table of Contents (2 of 2)

21 Surveillance

21-2 TRAFFIC SURVEILLANCE

21-2 Avoids fixing attention on any one thing for more than a few seconds

21-22 Responds promptly to attention-grabbing situation so eyes can move again

21-23 Observes traffic ahead, both parked and moving vehicles, to include cycles possibly obscured by larger vehicles (see 31, Following and 36, Reacting to Traffic)

21-24 Observes traffic behind by glancing through rearview mirror(s) frequently

21-25 Observes traffic from the side

21-251 Notes vehicles in adjacent lanes moving in same direction as car

21-252 Observes vehicles approaching from cross streets (see 41-15, Observes Other Traffic)

21-26 Watches other drivers' driving behavior for clues to how they react

21-261 Notes drivers who frequently change lanes as opposed to those who remain in lane

21-262 Notes drivers who drive with frequent changes in speed as opposed to those who maintain a steady speed

21-263 Notes those drivers who do not signal prior to a maneuver as opposed to those drivers who do signal consistently

21-264 Notes those drivers who stop suddenly (non-emergency) as opposed to those drivers who decelerate gradually to stop

36 Reacting to Traffic

36-1 REACTING TO OTHER VEHICLES

36-11 Reacting to Parked Vehicles

36-111 Drives at slower speeds when approaching or driving alongside parked vehicles

36-112 Watches for pedestrians or animals entering the roadway from in front or between parked vehicles

36-113 If approaching a parked vehicle with the hood up, decelerates and, if possible, positions car far enough away from parked vehicle to avoid striking its driver should he enter roadway

36-114 Watches for vehicle doors being opened or indications that vehicle occupants are about to exit on the roadway side

36-1141 Flashes headlight beams or sounds horn to provide warning

36-1142 If possible, positions car far enough away from the parked vehicle (lateral clearance) to avoid striking the vehicle door if it is opened unexpectedly

36-115 Looks ahead for indications of vehicles leaving parking spaces

36-1151 Notes vehicle with exhaust smoke coming from it

36-1152 Observes vehicle driver hand signals or directional turn signals which are activated

36-1153 Notes lighted vehicle back-up lights or brake lights

36-116 Prepares to stop behind or change lanes when vehicle ahead is about to exit or enter a parking space

41 Negotiating Intersections

41-1 APPROACHES INTERSECTION

41-11 Decelerates

41-111 Decelerates gradually but not too early, particularly if followed by another vehicle

41-112 Decelerates in sufficient time to avoid stopping in intersection or on crosswalk

41-12 Enters correct lane

41-121 Observes signs providing lane information

41-122 Enters correct lane as early as possible, but no later than 100 feet prior to intersection

41-1221 If proceeding through intersection

41-1221-1 Enters center lane(s) (unless otherwise directed)

41-1221-2 Enters left of two lanes

41-1222 Enters far right lane for right turn (unless otherwise directed)

41-1223 Enters far left authorized lane for left turn (unless otherwise directed)

41-13 Signals if intending to turn

41-131 Uses directional indicator or hand signal (see 14-2, Turning)

41-132 Gives signal at appropriate time

41-1321 Signals as soon as possible without causing confusion

41-1322 Signals no later than 100 feet prior to intersection

Why FCS Requires an Evolutionary Development Process

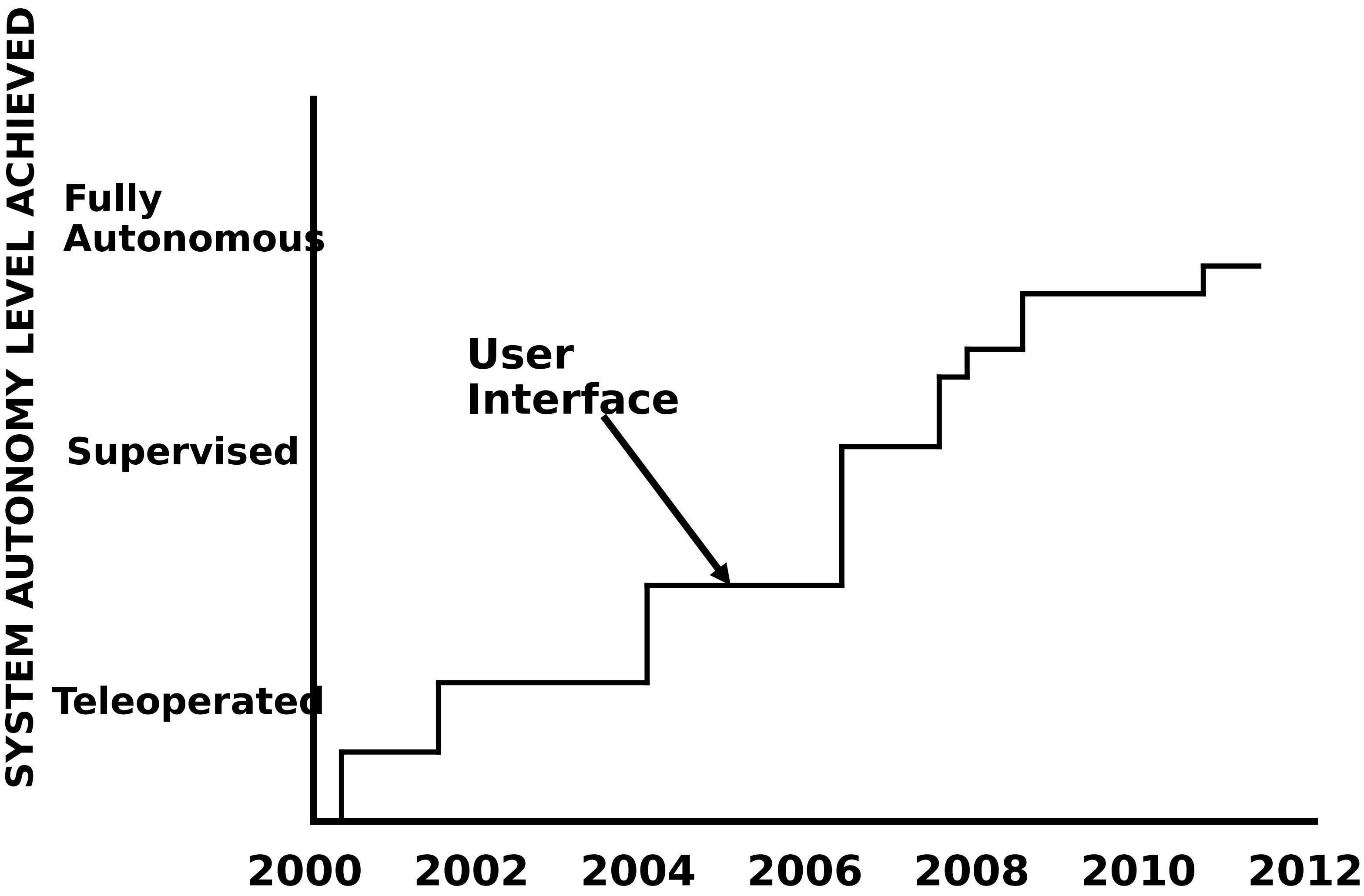
- **Technical Context**
  - Perception-based navigation technologies required to realize the full FCS vision will NOT be available before 2020
  - Moore's Law evolution of processing performance
    - 10 to 100 fold increase by 2012, 1,000 to 10,000 fold by 2025
  - Continuing rapid progress in sensor technologies
    - New product generations appear every 12-18 months
- **Programmatic Context**
  - Must respond to emerging/evolving requirements
    - Will be continuously modulated until deployment
  - Must produce information to support April 2003 development decision
  - Must support the development of system to meet initial 2010-2012 deployment
    - Can't afford to delay start until after April 2003 decision
  - Guidance from FCS SAG Report July 2000

From FCS SAG Report July 2000

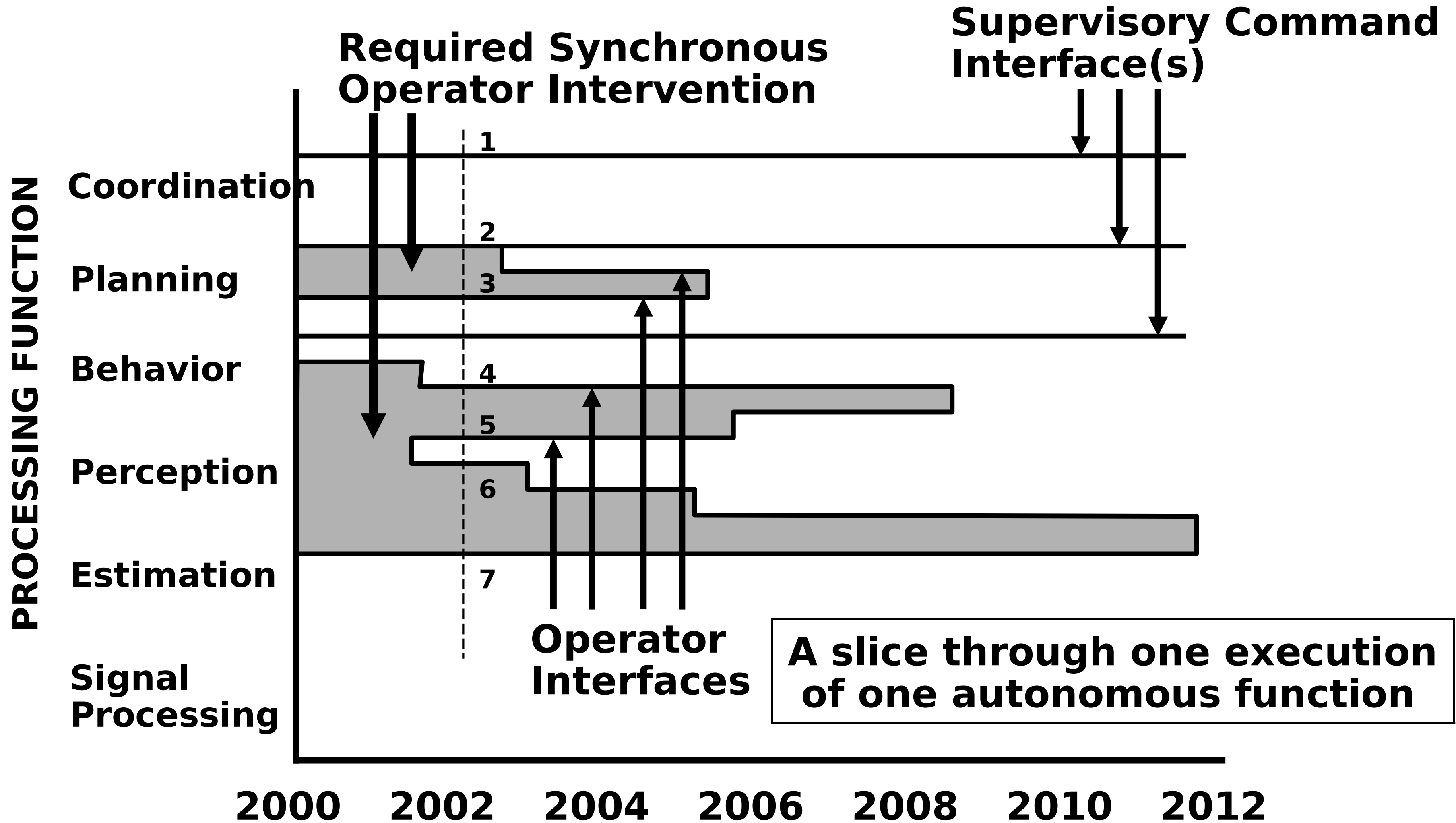
- **“The program office should define a clear and attractive strategy for continuing technologies that are important to FCS but which are not ready for 2003 date.**
  - **Robotics is a prime example”**

- **“Robotics has historically promised leap-forward goals, never succeeding although there are near-term payoffs. Step-wise goals will provide better management of expectations.”**

Evolution of Autonomy: Over-Simplistic View



Strategy: Evolutionary Elimination of Operator Intervention



Operator Intervention: Sample Execution Slice

1. **Supervisor orders a coordinated group move**
2. **Planner generates individual move commands, sends them to vehicles. Vehicle planner is unable to generate waypoints for move, prompts Operator**
3. **Operator generates list of waypoints, inputs to vehicle**
4. **Vehicle encounters a major obstacle, asks Operator for assistance**
5. **Operator clicks on an image point on the obstacle, commands follow-wall-on-left behavior**
6. **While following wall of obstacle, vehicle sensors “lose” the wall. Controller asks Operator for assistance**
7. **Operator designates several image points as**

Evolution of Human-Robot Interfaces Achieves…

- **“Mixed initiative” “Dynamic Autonomy” during ops**
  - **Supervisor tells robots what to do, based on tactical picture**
    - **Multiple Supervisor command levels**
  - **Operators <u>separate</u> from Supervisor ensure successful execution despite limitations of the system (Wizard of Oz)**
    - **Exploit perceptual capabilities of the Operator as required**
  - **Acknowledge that the system will <u>always</u> encounter limits to its autonomy**
    - **Build mechanisms into system architecture up front**
- **“Incremental Simulation” during development**
  - **Facilitate early exercise of system functionality in diverse environments**

Strategy: Evolution of Use of Deictic Percept-Referenced Commands

- **Sequence of Operator-input semantically-based Deictic commands**
  - **OP: Goto <click-on-image-point> Building**
- **Script including prompts for Operator-input non-semantic Deictic commands**
  - **SYS: (show image) “Click on Building for Goto”**
  - **OP: <click-on-image-point>**
- **Script including prompts for Operator-input OK or correction**
  - **SYS: (show image with building highlighted) “Goto this Building?”**
  - **SYS: display OK button and wait**
  - **OP: <click-on-OK> (or <click-on-alternate-image-point>**
- **Script including prompts for Operator attention (and override)**
  - **SYS: (show image with building highlighted) “Goto this Building”**

Percept-Referenced Navigation Commands

- Move Under <this> Vehicle
- Climb <how many> Flights Up <these> Stairs
- Climb <how many> Flights Down <these> Stairs
- Take <this> Elevator to the <number> Floor
- Cross <this> Street (and don’t get hit)
- Hide in <this> Vegetation
- Move Along <this> Wall (until…)
- Open <this> Door (and Enter… and Close)
- Move in <this> Direction (until…)

A Complex Command Behavior: Using an Elevator

- Take <this> elevator to the <number> Floor
  - No people present --> many people present
  - Single elevator --> double bank of elevators
- Issues
  - Manipulation: reach, strength, tactile/haptic feedback
  - Sensor viewpoint (e.g., be able to see indicators above door)
  - Perception: “understand” controls, indicators, auditory cues
  - Task planning, execution, monitoring: Press Up or Down? Get into this elevator? Press which floor button? Get off here?
- A “good” challenge
  - A useful real world human task with a good blend of complexity and structure, an easy tasking paradigm, and ease of testing

Perception of Relevant Environmental Features

- Enable robots to "perceive" many of the relevant environmental features that a human would use for navigation and mapping
  - Develop perception operators for relevant features/entities in a robot's environment
    - Replace existing placeholders in current research
  - Develop library of representations and abstractions to address the specific needs of FCS robotic navigation
  - Enable development of a family of robust perception-based navigational competencies

Robotic Perception in Human Terms

Environmental Features in a Spectrum of FCS Environments

- **Off-Road: Obstacle detection and avoidance**
  - Rock, grass, bush, tree, hole, slope, ditch, water, terrain traversability
- **Open Highway: Road following**
  - Pavement, lane, shoulder, intersection, ramp, obstacle, vegetation, other vehicle, pedestrian, signboard
- **Urban Streets: City driving**
  - Other vehicle, complex intersection, building, pedestrian
- **Close Quarters: Maneuver around buildings**
  - Road, parking lot, sidewalk, vehicle, person, animal, building, wall, door, fence, gate, grass, tree, bush, signboard
- **(Indoors)**
- **OTHER PEOPLE**

Reading Signs to Support Autonomy

- Sign Reader (SR) function employs the vehicle's sensor suite to detect, track, and "parse" any textual or graphic signboards in its environment
- SR provides vehicle controller with each sign's relative position, orientation, shape, size, color(s), text, and sign-type/sign-ID, if the sign matches an entry in its sign library (e.g., street sign, highway/STOP sign, commercial/McDonalds sign)
- Vehicle controller can then reason about the sign and its environmental context, and execute an appropriate behavior
- SR is highly relevant to indoor as well as outdoor navigation (e.g., hotel room numbers)

Reading Signs to Support Autonomy Development Agenda

- **Output of SR provides a well-defined perceptual-level input to autonomous planning resources**
  - **Precise, concise representation, meaningful to human operator**
- **Implementation of SR requires**
  - **Characterization of sensor inputs required by SR algorithms**
  - **SR algorithms development**
  - **World knowledge about signboards and how they are situated**
- **Using SR output for autonomous planning requires**
  - **World knowledge about signboards, how they are situated, and what they "mean"**
  - **Ability to perform sophisticated reasoning about the world, and the rich world knowledge resources necessary to support this reasoning, in order to execute the tactics, techniques and procedures required to perform our assigned task**

Strategy: Methodical Exploitation of Path-Referenced Behaviors

- The class of Path-referenced Behaviors
  - Leader-follower
  - Route replay
  - Retrotraverse
  - “Go back to <this> previous location” (path annotation)
  - Subtle sensitivities: sensor calibration, POV, lighting, etc
- Support tasking in terms of mission events
- Evolve from GPS-Based to Perception-Based
- System level capabilities, require stored data
  - Representation is key -- what level of abstraction?
  - Maximum leverage of limited perception capabilities
- Classic “what do you mean you can’t…” stuff

Path-Referenced Data

- Data items associated with the distance traveled along the path include:
  - Perceived location of features relative to path, classification, identification (includes obstacles and not-obstacles)
  - Absolute (compass) and relative (steering angle) path direction
  - Absolute (GPS) and relative (to other features) location
  - Terrain slope, side slope, surface characteristics, relative suggested speed of advance
  - Annotations derived from maps or input by operator (e.g., names, images, links)

Strategy: Implement High-level Mission-oriented Autonomous Tasks

- **Multiple coordinated robots, or single**
- **Mapping and monitoring building interiors**
- **Adaptive maintenance of communications connectivity**
- **Maintaining sensor/weapon coverage (e.g., self-healing minefield)**
- **Search (e.g., minefield breaching, demining, UXO disposal)**
- **Civilian: Agriculture (e.g., plowing, seeding, chemical dispensing, harvesting)**
- **…**

Summary: Strategies for Evolutionary Development

- Operator “behind the curtain”
- Percept-referenced commands
  - Separate perception of the referent from implementation of the behavior
- Path-referenced commands
  - Grounded in representations and abstractions
- Mission-oriented behaviors (one or more robots)

- Can we identify other “crutches” to facilitate the development process?
- How best to exploit learning techniques?

Approaches to Scoping the Development Job

- How can we determine how DIFFICULT the driving task is?
  - ALV plus 15 years of Moore’s Law
- How can we determine how BIG the development job is?
  - “Prairie Fire” metaphor
  - Driving Task Descriptions plus lessons from TMR
- If we had a dozen “son-of-UGCV” vehicles, complete with year 2012 computers and sensors, how long would it take for us to write the baseline driver software?
- How can we make a compelling case for the resources that will be required?
  - (an order of magnitude increase in robotics funding?)

We've been at this a while…

12 Electronic Engineering Times - Monday, January 30, 1984

DOD Targets 3 Projects For AI, Supercomputer Uses

By Chappell Brown

BOSTON — Lynn Conway, assistant director of strategic computing for the Department of Defense, outlined a broad-based program here last week to apply artificial intelligence and supercomputer technology to military systems.

Congress has approved $50 million in funding in fiscal 1984 for an initial project that targets development of three military artificial intelligence systems by technology and applications "communities," Conway said.

Projects Described

Conway, speaking at a VLSI conference at the Massachusetts Institute of Technology, said the systems to be developed initially include an autonomous land vehicle, a personalized adviser for jet pilots and an aircraft battle-management system.

Though Conway did not go into details about each project, in the past the Defense Department has said that the military would like a land vehicle that could roam a battlefield and detect enemy troops or equipment. The jet pilot's "adviser" will be an expert system giving instantaneous advice to jet pilots during flight, and a computerized battle management system would coordinate attacks from an aircraft carrier.

Military Applications

Conway said development of these systems would provide the basis of a "strategic computing" program that would develop technology of "unprecedented capabilities."

The program will focus on military applications that require machine intelligence and will draw on recent advances in computer vision, speech, and expert system technology.

Expert systems are a branch of artificial intelligence research that use databases derived from the experience of human experts to draw inferences in novel situations.

Conway used an incident in the Falklands war as an example, illustrating the use of this kind of system in a battle.

Falklands Incident Cited

British ships were using a computer-controlled radar system as a defense against Argentine aircraft. Although the system was highly advanced, the Argentinian pilots found a ploy that would confuse the system—they would fly in a tight pattern, appearing as a single object to the radar, and then quickly disperse.

This unexpected maneuver confounded the computer-controlled system. The experts needed to reprogram the system were all back in Britain.

What was required was an instantaneous expert at the scene, or, even better, a system that was more adaptable to novel situations, Conway said.

There are three broad technological goals of the strategic computing program: to provide the United States with a broad-based machine intelligence capability, demonstrate applications important to defense and provide technological spinoffs.

A fundamental theme of the project will be the interaction of advanced areas of research. For example, advanced VLSI architectures need to be combined with the kind of software and systems work being undertaken by artificial intelligence researchers. At this time, research groups such as these are not coordinated, Conway pointed out.

Applications 'Pull'

In Conway's view, specific programs—such as developing an autonomous land vehicle—impel this kind of cooperation; she spoke of applications providing the "pull" needed to create machine intelligence.

Although DARPA (Defense Advanced Research Projects Agency) will manage the project, approximately 10 "computer technology communities" will be created to develop the required technology and another five to 10 "applications communities" will work on implementation. Each community will involve 100 professionals from private, academic and government areas.

A high degree of interactivity will be crucial to the project, and networks and interactive workstations will be heavily used. Conway used the phrase "an online window into activities."

Although the need for secrecy on defense projects might work against this open communications network, Conway replied that only the specific applications communities would be operating under classified information restrictions. The basic technology development program would be open.

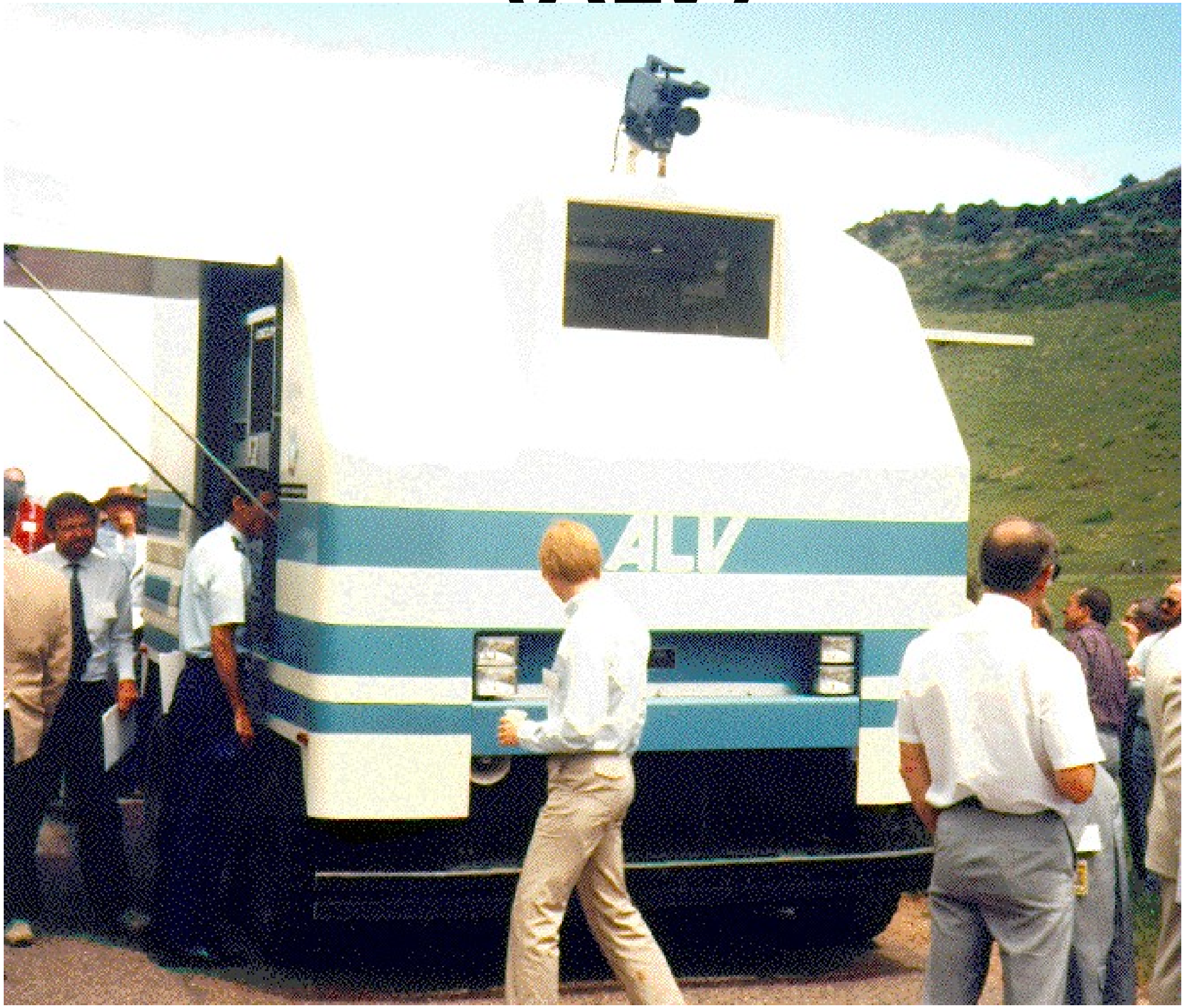
The plan calls for $50 million in 1984, $96 million in 1985 and $150 in 1986.

Japanese Reveal VLSI Thrusts

Apple: Mac Won't Repeat

(announcement of DARPA ALV program, January 1984)

Autonomous Land Vehicle (ALV)

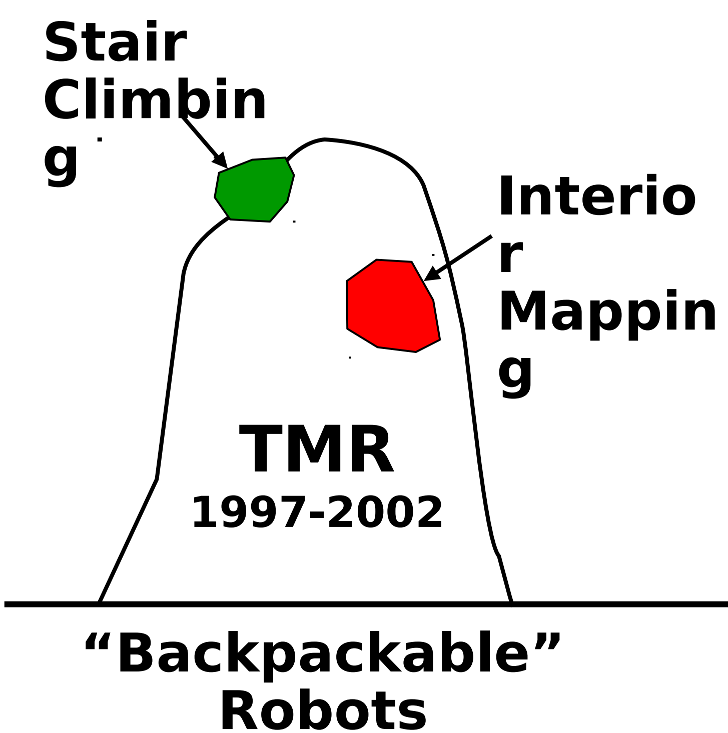


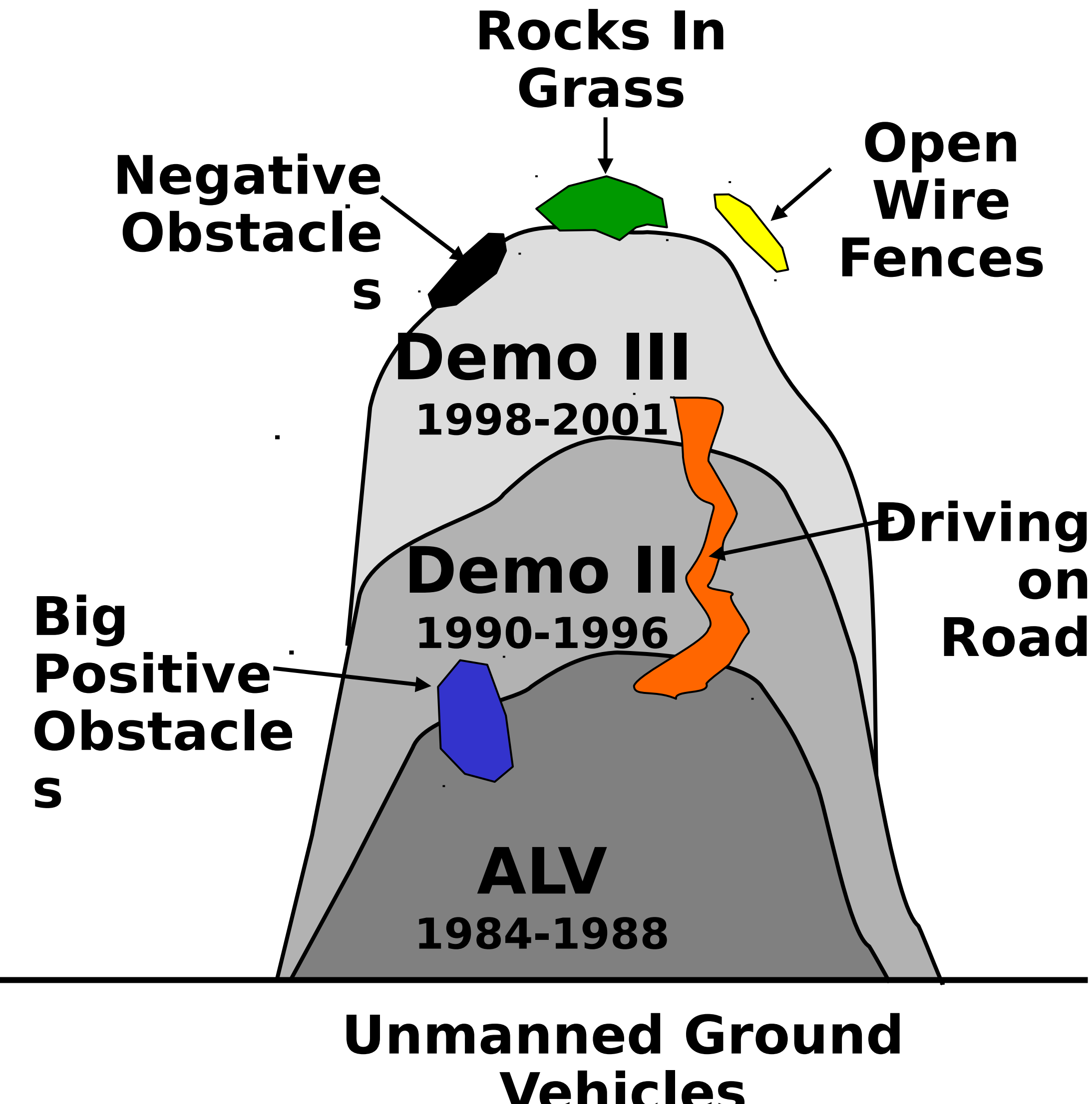
A Lesson from ALV?

- **Autonomous Land Vehicle began in 1984, with goals that arguably have not yet been realized 15 years later**
  - **Not from want of trying: Demo II, Demo III, others**
  - **15 years of Moore's Law progress: factor of 100 to 1000**
- **If we were that far off in assessing the difficulties of the problem in 1984, what makes us think that we are any smarter today?**

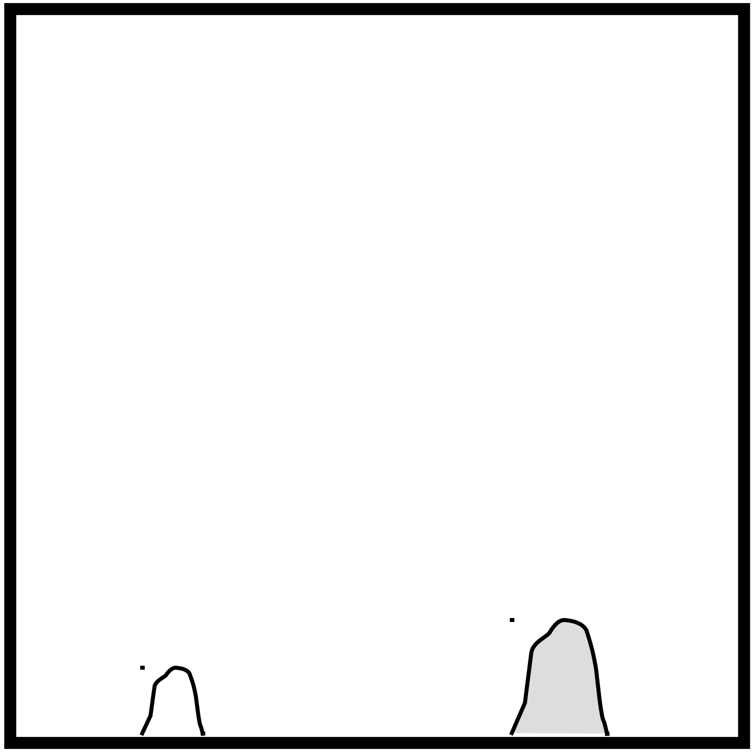
A Prairie Fire

Progress of Robotic Technology Programs
“Prairie Fire” Metaphor



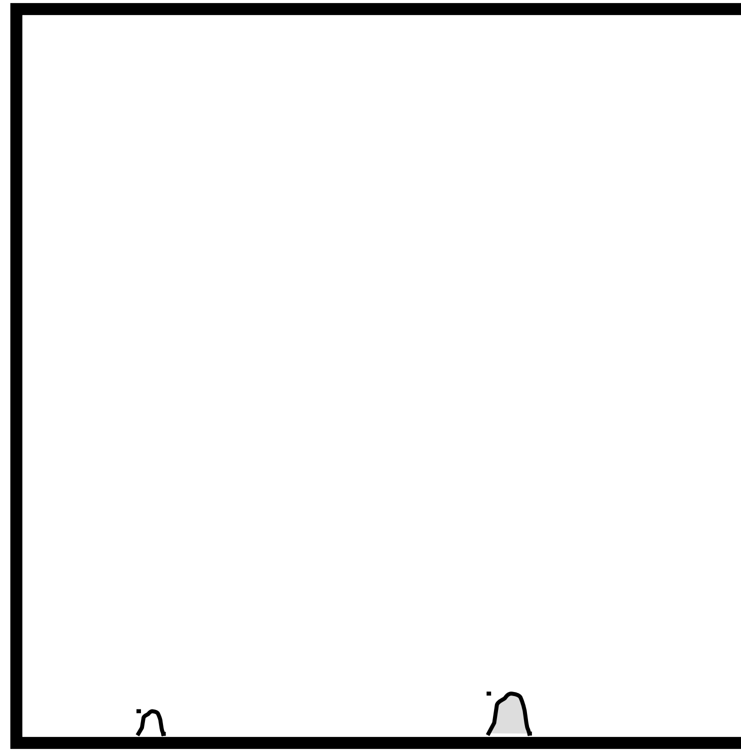


How Big Is the Whole Job?



OR

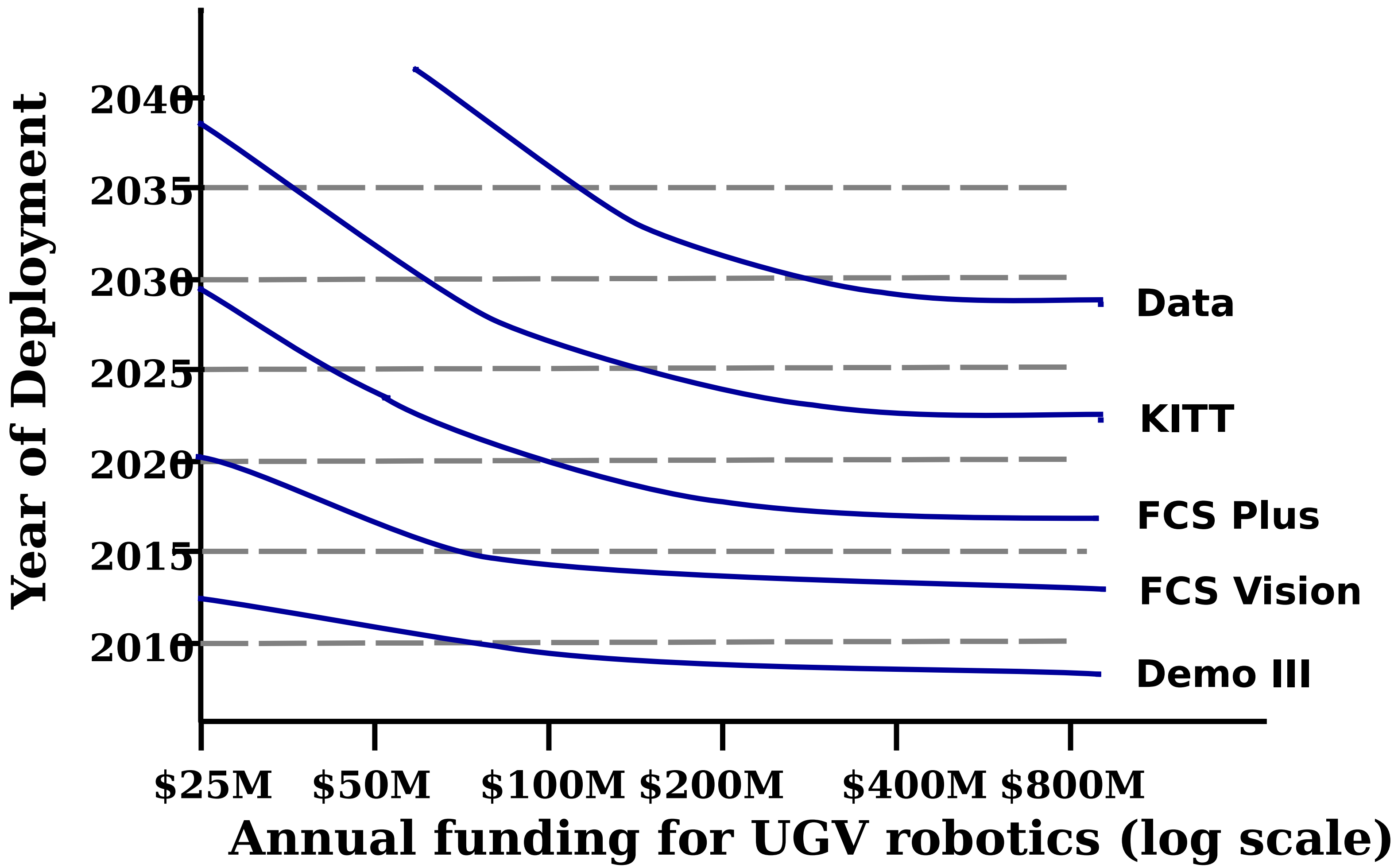
?



What are the hazards we haven’t hit yet?

Should’t we “start more fires”?

Increased Resources Hasten Capabilities



(What does this chart *really* look like?)

Summary

- Non-military on-road autonomous driving capability
  - Necessary for FCS (but not sufficient)
  - Rich “anthropomimetic” capability
  - Identifiable subgoals (sightseer, parker)
- Strategies for evolutionary development
  - Operator “behind the curtain”
  - Percept-referenced commands
    - Separate perception of the referent from implementation of the behavior
  - Path-referenced commands
    - Grounded in representations and abstractions
  - Mission-oriented behaviors (one or more robots)
- Scoping the development job
  - How difficult, how many lines of code?
  - How much will it cost, how long will it take?